IS THERE EVIDENCE FOR DISK-HALO CONNECTIONS IN M31 ?

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ABSTRACT. There is some evidence for disk-halo connections in M31, i.e.: (1) The central area seems inclined w.r.t. the main disk. (2) In several regions in the southern half the magnetic field has a significant component perpendicular to the disk. However, (3) any general emission from a thick disk at λ75 cm is ~100x weaker than that from our Galaxy. The uniform disk field seems to inhibit cosmic-ray diffusion perpendicular to the plane, and/or the field at high z is exceptionally weak.

1. CENTRAL AREA

Beck et al. (1989) showed that the projected uniform magnetic field ($B_\perp$) runs along the Hα-arm at about 2' (400 pc) south and east of the nucleus (Ciardullo et al., 1988). If this arm is seen from an angle of ~20° it would be ~55° inclined to the main disk of M31. North of the nucleus many thin Hα filaments are seen, typically 0.5 kpc long. These filaments possibly stick out of the main disk with inclinations of ~30°. If the magnetic field runs along the filaments, the complicated structure in the radio beam could account for the non-detection of polarized emission at λ20 cm in this area.

2. DISK

In Fig. 1 the magnetic field structure within 30' from the minor axis (Berkhuijsen et al., 1987) is shown superimposed onto the distribution of integrated HI of Brinks and Shane (1984). The field is generally aligned with the spiral arms, but some deviations are noticeable.

Near the edge of the map in the southwestern quadrant part of the field lines is orientated along an HI bridge connecting the brightest inner arm with an outer arm. This quadrant was also observed at λ20 cm with the VLA; the field structure at a resolution of 3' derived from a comparison with the λ6.3 cm data taken at Effelsberg (Berkhuijsen et al., 1987) is in good agreement with that shown in Fig. 1. Beck et al. (1989)

H. Bloemen (ed.), The Interstellar Disk-Halo Connection in Galaxies, 233–236.

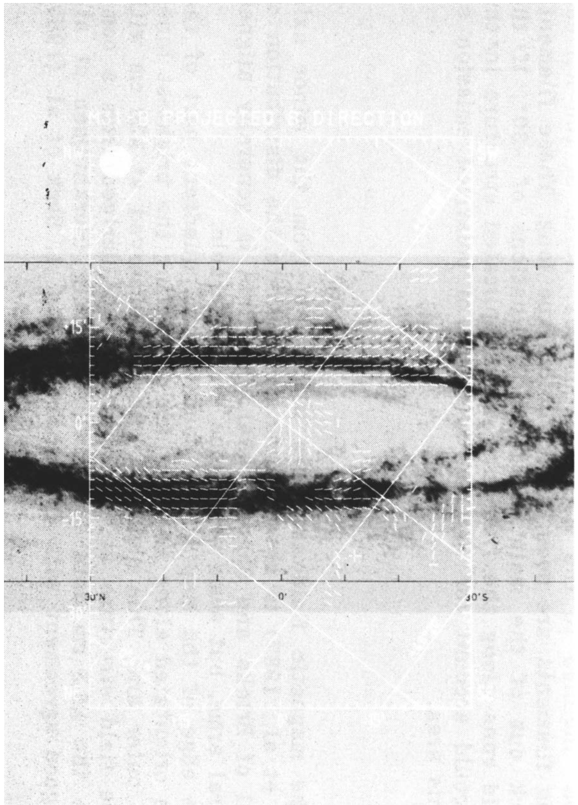

Figure 1. Distribution of $B_\perp$ superimposed onto the integrated HI distribution.

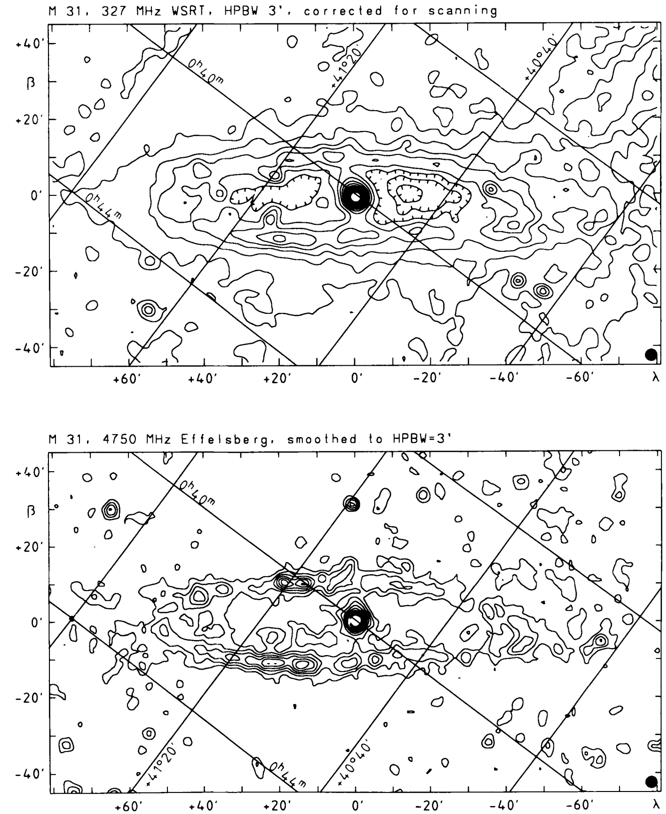

Figure 2. Radio continuum map of M31 (HPBW = 3') at: (a) λ92 cm, contour levels 5 (= 1.4σ), 20, ..., 215 mJy/beam, hatched contours enclose minima; (b) λ6.3 cm, contour levels 2.5 (= 2.2σ), 4.5, ..., 22.5 mJy/beam.

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could explain the distributions of $B_\perp$ and of the rotation measures (RM) by a magnetic loop coming out of the plane, a structure reminiscent of a Parker–Jeans instability.

Field lines strongly deviating from the arms are also seen in the southeastern quadrant of Fig. 1. Interestingly, spurs perpendicular to the arms in the distributions of cool dust (Walterbos and Schwering, 1987) and blue light (Walterbos and Kennicutt, 1987) have been detected, which are coincident with the magnetic field deviations near $(\lambda,\beta) = (-9',-20')$ and $(-27',-15')$. The authors note, however, that these spurs could be foreground structures in the Milky Way. Another remarkable fact is the large 'hole' on the spiral arms between $\lambda = -15'$ and $-35'$ in the $^{12}CO(1-0)$ distribution of Dame et al. (1991). In this area the number of massive molecular clouds may be too small to keep the magnetic field in the disk (Beck et al., 1991; Beck, 1991).

3. THICK DISK AND EXTENDED HALO

Recently, Golla and Walterbos (in prep.) completed a map at λ92 cm of M31 with the Westerbork interferometer. After subtraction of unrelated point sources this map was smoothed to a resolution of 3' for comparison with the Effelsberg map at λ6.3 cm (Fig. 2a and 2b). Both maps show extended minima on either side of the nucleus. Although these minima contain dust and stars they emit very little nonthermal emission. An upper limit to the thick-disk emission was estimated by taking a 10' wide cut through the southern minimum perpendicular to the major axis (Fig. 3). At λ92 cm the emission from the minimum is < 10 mJy/b (= 5 K), whereas that at λ6.3 cm is < 0.5 mJy/b (=1.1 mK = 1σ). Hence, the flux density spectrum has a slope steeper than 1.1. These values are consistent with the estimate of < 2 K at 408 MHz at $\lambda = -15'$ with a 4'.5 beam by Gräve et al. (1981). This upper limit for the emission from a thick disk in M31 is ~100x less than the emission from the thick disk of our Galaxy (Beuermann et al., 1985, Fig. 9) and > 200x less than that of NGC 891 (Hummel et al., 1990) at 408 MHz.

Weak evidence for an extended halo of < 4.2 K at 408 MHz and a diameter of 2°.4±0°.1 has been given by Gräve et al. (1981). Such a halo would not be detectable in our maps.

The distribution of the emission at λ92 cm is much broader than that at λ6.3 cm (Figs. 2

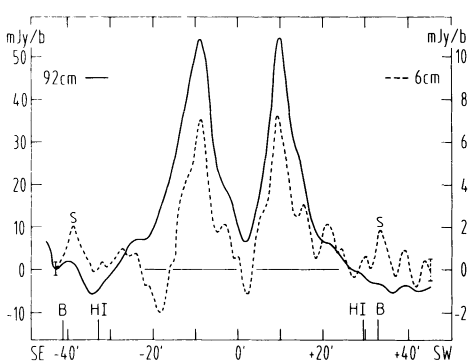

Figure 3. Cuts through the southern minimum perpendicular to the major axis averaged between $\lambda = -8'$ to $-17'$. At λ92 cm the emission at $\lambda > 20'$ is influenced by a ripple in the background. At λ6.3 cm s = unsubtracted point source.

and 3) suggesting that the high-energy electrons have suffered diffusion losses. This is supported by the spectral distribution along the cuts in Fig. 3 with typical values of $\alpha = 0.73$ on the emission peaks steepening to $\alpha = 1.0$ to 1.1 on the relative minima in the emission ring at λ6.3 cm. If the nonthermal spectral index $\alpha_{nth} = 1.0$ the fraction of nonthermal emission at λ92 cm is > 90% and at λ6.3 cm > 40%. Assuming that the distribution at λ6.3 cm reflects the distribution of the sources of relativistic electrons the observed differences in width may be used to estimate the diffusion length of the electrons. The beam-corrected half-widths in Fig. 3 are 9!5 and 6!1 in the SE and 6!9 and 4!0 in the SW at λ92 cm and λ6.3 cm, respectively. If the diffusion were entirely *in* the plane of M31 (distance = 690 kpc, inclination of ring = 74°) the full half-width is 2.1 to 2.5 kpc larger at λ92 cm than at λ6.3 cm, yielding diffusion lengths of ~1 kpc. Similarly, if the diffusion were entirely *perpendicular* to the plane the diffusion length is ~0.3 kpc. In this case the full thickness of the nonthermal emission in z at half intensity is 2 kpc in the SE and 1.4 kpc in the SW.

The exceptionally weak emission at high z of M31 may be a consequence of the high uniformity of the magnetic field parallel to the spiral arms, which hampers cosmic-ray diffusion perpendicular to the arms, and/or of a weak magnetic field in the thick disk (Beck, 1991).

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